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Comparative tree height measurement using different instrument

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Abstract
The height measurement is very complicated and time consuming job in forestry. The measurement value may differ with use of different instruments but research related to this using different instrument wasn't conducted so far in Nepal. Thus, this research was objectively carried out to assess the variation in height measurement using Clinometer, Rangefinder and Abney level and error caused by the use of instruments, their precision level in height measurement to find the most efficient instrument for measurement. Satyadevi community forests in Chitwan district was selected as the study site. Total 110 healthy plants were measured, representing different diameter class 5 cm and above 55 cm with interval of 5. Each class consist 10 plants whose heights were measured. The bamboo pole was used to find the actual height of the plant for diameter class 5-30 cm. The measurement of big diameter class was measured applying destructive techniques. The time was recorded for each measurement according to instrument used. Data were analyzed using statistically to compare the height using different instruments with actual measurement. Error was estimated using the differences between the values and precision was also calculated. The time efficiency was calculated using mean time and estimator $(E\%)^2 \times T$. Furthermore, the regression analysis was done to show the correlation between actual height and estimated height measured by instruments. The result showed that, the average value of height of plants were 5.42 ± 1.77, 5.57 ± 1.47 and 5.17 ± 1.7 m using Clinometer, Rangefinder and Abney level respectively in 5-10cm diameter class which values were 23.81 ± 1.77, 21.79 ± 1.47 and 22.98 ± 1.7m measured by Clinometer, Rangefinder and Abney level respectively in diameter >55 cm. The differences in mean value between diameter class 5 to >55 cm with comparison to true height measured with Clinometer ranges from 0.16 to 2.74 m whereas measurement with Rangefinder ranges from 0.12 to 1.22 m and 0.10 to 1.88 m for Abney level. The average error percentage is lower with the measurement taken by Rangefinder with the value 2.95% and higher with the measurement taken by Clinometer with the value 8.27%. The average error percentage of measurement taken with Abney level is 4.31%. The average precision of height measurement with instruments shows that Rangefinder is higher than Abney level and Clinometer with very small difference of 0.01 and 0.005 simultaneously. The Rangefinder is the most efficient height measuring instrument since the efficiency value was found to be lowest 842.08 in comparison to estimated value of it using Clinometer and Abney level with 8029.30 and 2378.42 respectively. Since, R^2 value of true height and measured height using Rangefinder was 0.70 whereas Clinometer was 0.66 and of Abney level was 0.61. It was found that, measured height using Rangefinder performed the most correlated with true height of the plant. This research will be useful for choosing the instrument according to precision and time efficiency required.

Keywords: instruments, height measurement, precision, bias, time efficiency

Introduction

The basic parameters are height, girth and crown spread to quantify the size of a single tree. Generally, girth of the stem and height of a tree are used to estimate basal area, wood volume, biomass, carbon, life history, productive capacity and growth of stem (Shugart *et al*., 2010) [51]. Height measurement of the plant is importantly vital one next to diameter measurement. A small error in height measurement can significantly affect the volume, biomass estimation and vice versa (Goodwin, 2004, Bragg, 2007, Larjavaara and Landau, 2013) [26, 9, 40].

Among all parameters, the diameter is easy to measure but remaining ones are complex to do so. Several techniques and technologies have been developed to measure the height of the trees. Broadly, direct and indirect measurements are common practice in forest inventory. The direct measurement of height is worthwhile only to measure tree height below 10 m particularly using ladder or labeled pole or dropping the tape from top (Goodwind, 2004) [26]. On the other hand, indirect measurement is the use instrument based on trigonometrical and similar triangle principles (Powell, 2017) [57].

Initially, height of trees was measured using the direct method and ocular estimation method. The result was very rough and imprecise. So, the instrument base height measurement become gradually popular in forest inventory (Korning and Thomsen 1994) [58]. However, the used instruments are the traditional one like Abney's level, Clinometer and Silva which requires the distance measurement because these instruments can only measure the top angle of the tree. Still, developing countries like Nepal still have been using these instruments. Consequently, the precision level will be low in some contexts.

It is highly important to measure individual tree attributes accurately and precisely (Louma *et al*., 2017) for different purposes (Laar and Akça, 2007). Many instruments are capable of high accuracy under optimum operating conditions but may create inconvenience under normal stand conditions that their

actual operating will be low (Rennie, 1979) [47]. Measuring the height of standing tree, whose top and bottom are well defined and clearly visible, the existing instruments are adequate (Hunt, 1958, Warren, 1959, Rennie, 1979) [33, 53, 47]. However, the variance and bias of height estimate could be large for tall trees in dense stand or for trees which do not have well defined tops (William *et al*., 1994) [55].

These days, they have been using the laser based instruments like Vertex and Range finder to measure the height of the tree directly without measuring the distance (Goodwind 2004, Avery and Burkhart 2011) [26, 3]. At the same time, these instruments are considered to be very precise one. However, forestry professional in Nepal still using the traditional instruments. The small bias in height measurement will have cumulative effect on several calculation and ultimately the plan preparation and implementation plan as well (Rennie, 1979) [47]. Such types of research is lacking in Nepal. Thus, this research was objectively carried out to compare the height measurement using Clinometer, Rangefinder and Abney level, and associated error and precision level in the measurement. Height measurement.

Methodology

Study Area

Satyadevi Community forest of Chitwan district was selected as my study site in Province No. 3. Its latitude is 27°36′21.60″ north and longitude is 84°22′47.28″ east. It lies in the elevation range of 141-1147m. Out of the total land area, the forest area covers 65.8% (1, 47,490 ha) of the district. This forest is situated at ward no. 2 of Rapti municipality and total area of this is 491.03 ha. There are 223 users of this forest but the productive area of the forest is 195.98 ha. Slope range of the CF is 0˚-19˚. The selected community forest is natural mixed *Shorea robusta* forest having *Terminalia tomentosa, Schima wallichi, Lagerstromia parviflora, etc.* are as associate spp. The main NTFPs found in CF are *Terminalia chebula, Terminalia belerica, Emblica officinalis, Bambusa vulgaris* etc. The wild lives are leopard, monkey, fox, deer, crow, cuckoo, peacock, python etc. in the forest (figure 1).

A preliminary survey was done to conceptualize the situation and to identify the appropriate site for field data collection. The purposive sampling was applied to collect data. So, 110 plants were selected representing different DBH class specifically 5 to 55 cm and over, maintaining 5 cm class interval. Infact, height of 10 plants were measured from each diameter class. These data were classified into 11 diameter class.

Moreover, the pole was used to find true height of the small plants. The big trees were measured after felling them. Next, the height of these plants was measured using Clinometer, Abney's level and Powerline 660 Rangefinder simultaneously. The upslope side was used as a reference for tree height (Larjavaara and Muller-Landau 2013) [40]. Total time required for plants height measurement using instruments were also recorded to compute the efficiency.

Data analysis: The collected data were analyzed using simple trigonometric calculation using. Moreover, the precision and efficiency were also calculated to compare the height measurements from different instruments with true measurement.

Bias = True height – Measured height by instrument (Larsen *et al*., 1987) [41]

Precision^2 = (Accuracy)^2 - Bias^2 (Hush *et al*., 2003)

Efficiency was compared using the $E^2 \times T$ (Bonyad and Mirzaei, 2016) [8] where E is the percentage of sampling error and T is total time for measurement.

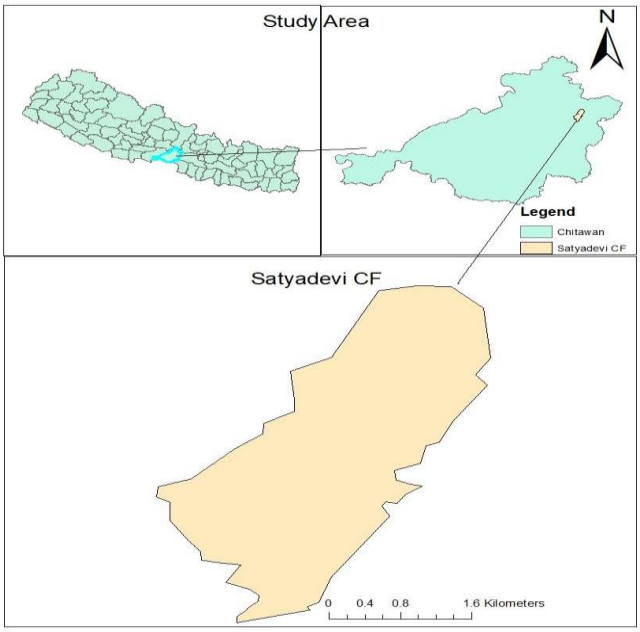

Fig 1: Map of Study Area showing Nepal, Chitwan district and Satyadevi Community Forest

Shapiro-Wilk test was conducted to examine the normality of the data. Since, the data were normal, One-way ANOVA was used to calculate the correlation between true height and measured height (Kothari, 2004) [37].

Result

Comparison of height measurement using Clinometer, Rangefinder and Abney's level as per diameter class

The height of plants using different instruments i.e. Clinometer, Rangefinder and Abney level that varies from actual height of plants, categorized according to diameter class. In case of 5-10 cm DBH class, the average value of height of plants measured by Clinometer was 5.42 ± 1.77 m, measured by Rangefinder was 5.57 ± 1.47 m and Abney level was 5.17 ± 1.7 m. Since the average value of actual height of this DBH class was 5.27 m, the value of height of plants varies among each other. Similar pattern was found in case of other diameter class interval. In case of DBH>55 cm class, the average value of height of plants measured by Clinometer was 23.81 ± 1.77 m, measured by Rangefinder was 21.79 ± 1.47 m and Abney level was 22.98 ± 1.7 m. Since the average value of actual height of this DBH class was 22.39 m, the value of height of plants varies among each other (Table 1).

One-way ANOVA showed that, there was no statistically significant difference in height measurement using Clinometer, Rangefinder and Abney level while measurement compared with actual height as shown in case of all DBH class interval.

Table 1: Comparison of actual height and estimated height measured with Clinometer, Rangefinder and Abney level

DBH class (cm)	Actual height (m)	Height using Clinometer (m)	Height using Rangefinder (m)	Height using Abney level (m)
5-10	5.27	5.42±1.77	5.57±1.47	5.17±1.7
10-15	9.39	9.95±1.77	9.78±1.47	9.53±1.7
15-20	12.65	13.58±1.77	13.56±1.47	12.85±1.7
20-25	14.04	15.25±1.77	14.75±1.47	14.65±1.7
25-30	14.64	16.58±1.77	15.64±1.47	15.89±1.7
30-35	15.07	16.62±1.77	16.24±1.47	15.97±1.7
35-40	17.55	19.47±1.77	18.19±1.47	18.32±1.7
40-45	21.11	22.44±1.77	20.91±1.47	21.60±1.7
45-50	16.53	19.14±1.77	16.41±1.47	18.41±1.7
50-55	21.89	24.64±1.77	20.67±1.47	23.53±1.7
>55	22.39	23.81±1.77	21.79±1.47	22.98±1.7

Error in height measurements using Clinometer, Rangefinder and Abney level

The differences between true value and height measured with Clinometer ranges from 0.16 to 2.74 m among DBH class 5 to 55 cm and more whereas measured with Rangefinder ranges from 0.12 to 1.22 m. The error using Abney level measurement error ranges from 0. 10 to 1.88 m in height measurement (table 2).

Table 2: Differences in height measurement using Clinometer, Rangefinder and Abney level with actual height in respective DBH class

DBH class	Differences in height measurements					
	TM-CM		TM-RM		TM-AbM	
	Diff	%	Diff	%	Diff	%
5-10	-0.16	2.43	-0.31	5.76	0.10	2.59
10-15	-0.56	6.04	-0.39	4.37	-0.14	1.68
15-20	-0.92	7.74	-0.91	7.59	-0.20	1.97
20-25	-1.21	8.69	-0.71	5.50	-0.61	4.77
25-30	-1.94	12.93	-1.00	7.06	-1.25	8.13
30-35	-1.55	11.46	-1.17	7.73	-0.90	7.16
35-40	-1.92	12.43	-0.64	4.42	-0.77	6.04
40-45	-1.33	6.89	0.2	0.25	-0.49	3.03
45-50	-2.61	16.19	0.12	1.29	-1.88	12.07
50-55	-2.74	12.97	1.22	5.44	-1.64	8.28
>55	-1.42	6.86	0.6	2.99	-0.59	3.13
Average	-1.49	8.27	-0.27	2.95	-0.76	4.31

Note: TM= true measurement, CM= Clinometer's measurement, RM= Rangefinder's measurement and AbM= Abney's level's measurement

The average error percentage was 2.95 % the least in height measured using Rangefinder. The errors were 8.27 % and 4.31 % in height measured using Clinometer and Abney level respectively. Likewise, average differences between measured height using instruments and true height was high 1.49 m using Clinometer and the least 0.27 m using Rangefinder.

Precision level in height measurement using Clinometer, Rangefinder and Abney level

The average precision of height measurement with instruments shows that Rangefinder is higher than Abney level and Clinometer with very small difference of 0.01 and 0.005 simultaneously. Thus, due to very small differences in precision, instruments are equally precise (Table 3).

Table 3: Precision level of plants height measurement using Clinometer, Rangefinder and Abney level according to DBH class

Precision level of plants height measurement using Instruments			
DBH class	Using Clinometer	Using Range finder	Using Abney level
5-10	5.19	5.18	5.19
10-15	9.37	9.38	9.39
15-20	12.62	12.62	12.65
20-25	13.99	14.02	14.03
25-30	14.51	14.61	14.59
30-35	15.45	15.46	15.43
35-40	17.44	17.54	17.53
40-45	21.07	21.11	21.10
45-50	16.32	16.53	16.42
50-55	21.84	21.86	21.83
>55	22.34	22.38	22.38
Average	15.46	15.51	15.50

Efficiency of instruments used for height measurement

The estimated $E^2 \times T$ for height measurement by Rangefinder was the lowest with value of 842.08 in comparison to Clinometer and Abney level with value of 8029.30 and 2378.42 respectively. Thus, it can be concluded that Rangefinder was the most efficient instrument (table 4).

Table 4: Calculation of $E^2 \times T$ for computing Efficiency of plants height measurement using Clinometer, Rangefinder and Abney level

Instruments	$(E\%)^2$	T(min)	$(E\%)^2 \times T$
Clinometer	77.87876	103.10	8029.30
Range Finder	16.93749	49.72	842.08
Abney level	18.55241	128.20	2378.42

Relationship between actual height and measured height

The R^2 values were used to show the correlation between true height and height measured by instruments: Clinometer, Rangefinder and Abney level. Larger R^2. Averaging R^2 value of correlation between true value and height measured using Rangefinder was 0.70 whereas the R^2 values were 0.66 and 0.61 for the values of Clinometer is of Abney level respectively.

Table 5: R^2 value showing correlation between True height and estimated height measured using Clinometer, Rangefinder and Abney level

DBH class	R^2 value		
	Actual Vs Clino	Actual Vs Range	Actual Vs Abney
5-10	0.9714	0.9459	0.9536
10-15	0.3744	0.3059	0.2581
15-20	0.523	0.6931	0.5172
20-25	0.7099	0.528	0.6088
25-30	0.8758	0.8752	0.8555
30-35	0.0603	0.7137	0.0618
35-40	0.5545	0.7628	0.4848
40-45	0.6574	0.6083	0.6193
45-50	0.8677	0.9403	0.8884
50-55	0.83	0.5816	0.6675
>55	0.8245	0.778	0.7473
Average	0.66	0.70	0.61

Discussion

The result obtained from the collection and analysis of data showed the significance of the study. There was variation in Plants height while measured by Clinometer, Rangefinder and Abney level. Though varied plants height, One-way ANOVA test resulted insignificance difference at 95% confidence level between true and estimated height measured using Clinometer, Rangefinder and Abney level. Although there was no significant difference between measurements with different instruments and actual height there was small differences between true height and measured height. There was not much deviation in precision level among each instrument. To aid in instrument selection efficiency with respect to comparison of mean time taken by instrument for measurement and calculation of (E %) ^{2}*T was analysed that resulted Rangefinder to be the most efficient instrument.

Variation in height measurement using Clinometer, Abneys level and Range Finder

Though no statically significant difference, it showed there was variation in height measurement using Clinometer, Rangefinder and Abney level while comparing measured height with actual height. This may be due to the different function of instruments while taking measurements. Solomon and Nolet (1968) studied reliability of tree height measurement in Northern hardwood stands. No significant differences were found between the heights of standing hardwood trees estimated with a Haga altimeter and actual heights measured after the trees had been felled.

Thus there is no significant differences in measurement though plant's height measured using varied instruments.

Error in height measurement using Clinometer, Rangefinder and Abney Level

In study of Bragg (2008) [9], the sine method being insensitive to the primary sources of measurement error using the tangent method, had noticeably less difference in the estimated heights of the pine trees. Both trees had a particular direction for which the tangent error was greatest. Larjavaara and Muller-Landau (2013) [40] compared sine method to the traditional method for height measurement and showed that the tangent method resulted in large errors than sine method

Precision level of height measurement using Clinometer, Rangefinder and Abney level

As stated in the finding of Louma *et al*. (2017), the size of the tree (DBH or height) did not affect the precision level at field measurements. There was little variation in relative standard deviation for tree height between the groups of different sized trees in both DBH- and height-based size classes. The study done by Clark *et al*. (2000) [17], Liu *et al*., (2011) [42], William *et al*., (1994) [55] showed that the measurements of the same trees using several devices, such as a caliper and diameter tape, or a Laser height finder and a Clinometer, but no major differences in precision have been reported.

Time Efficiency for height measurement using Clinometer, Rangefinder and Abney level

As there is inverse relationship between sampling efficiency and time (Messavage and Grosenbauch, 1956 [43] as cited in Pellico Netto *et al*., 2014) [46], time was used for the analysis of time efficient instrument. To select the most time efficient instrument among three instrument Clinometer, Rangefinder and Abney level, mean time were calculated for each instrument. The lowest time was taken by Rangefinder with mean time of 27.12 sec and that of Clinometer and Abney level was 56.34 sec and 70.18 sec with the order respectively.

The study of Rennie, (1978) [47] found Clinometer to be faster than measuring with Abney level. When using a tape, Rennie (1978) [47] found the use of the Suunto clinometer with tape to be a faster instrument to determine tree height than the Abney level or Blume-Leiss.

Conclusion and Reccommendation

- Comparison of instruments Clinometer, Rangefinder and Abney level for height measurement of tree give us the idea to explore more about the instrument selection for proper use in forest inventory.
- The error percentage in height measurement using Clinometers was high within diameter class of 5 cm and 55 cm above whereas this was least in height measurement using Rangefinder.
- Similar value of precision level of instruments Clinometer, Rangefinder and Abney level were not significantly different.
- Rangefinder was the most time efficient instrument in comparison to Clinometer and Abney level.
- Actual height highly correlates with estimated height measured with Rangefinder whereas least with Abney level.

This study is done in plain areas so it should be carried in hilly terrain too to examine the error and precision level of height measurement. Each height measurement should be operated with careful consideration.

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